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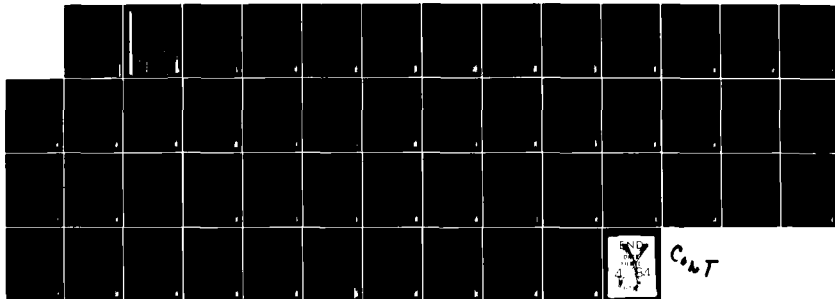
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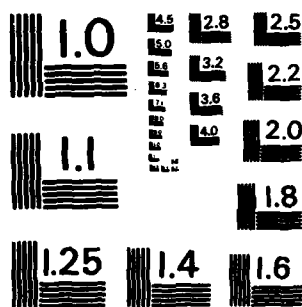
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AN EXAMINATION OF STRATEGIES
FOR TECHNOLOGICAL AND
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MUNITIONS PRODUCTION IN
AUSTRALIA DURING WORLD WAR II

BY A.T. ROSS

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CSE NOTE 51
JANUARY 1984

AN EXAMINATION OF STRATEGIES FOR TECHNOLOGICAL AND
INDUSTRIAL SUPPORT FOR MUNITIONS PRODUCTION
IN AUSTRALIA DURING WORLD WAR II

A.T. ROSS

SUMMARY

This Note is a development of work carried out by CSE in 1981 to assist the Defence Working Group on Gun and Rocket Propulsion Technology. The author derives strategies available to a small power for the establishment of technical knowledge of munitions and the subsequent development of mass production. Australian preparation and experience in World War II is treated as a case study to determine the more robust of the strategies.

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CONTENTS

	Page No.
INTRODUCTION	1
Explanation of Terms	1
The Requirement to Modify Proven Munitions	2
Derivation of Strategies of Technological and Industrial Support	4
The Impact of Time Constraints on Strategies	6
The Australian Experience	7
STRATEGIES OF TECHNOLOGICAL AND INDUSTRIAL SUPPORT FOR THE AUSTRALIAN DEFENCE FORCES DURING WORLD WAR II	9
Introduction	9
Strategy of Self Containment	9
Strategy of In-Country Research and Development	11
Strategy of In-Country Production Design	13
Strategy of the Technology Package	13
MEASUREMENT OF EFFECTIVENESS	15
Introduction	15
Quality and Reliability	15
Mass Production	16
Timeliness	18
Application of Measures of Effectiveness	18
RESULTS	19
The Scope of Research and Analysis	19
Success in Quality and Reliability	19
Success in Mass Production	20
Timeliness of Mass Production	21
Summary of the Gun, Small Arms and AFV Production Projects	25
Significance of Critical Path Delays	27
The Influence of Munition Complexity	30

CONTENTS (Cont'd)

	Page No.
Trends in Other Areas - Aircraft	32
Trends in Other Areas - Optical Munitions	35
Trends in Other Areas - Ammunition and Explosives	35
SUMMARY AND CONCLUSIONS	36
World War II Experience	36
Continuing Relevance of the Wartime Strategies of Technological and Industrial Support	38
REFERENCES	40

LIST OF TABLES

1. THE RELATIONSHIP BETWEEN THE STRATEGIES OF TECHNOLOGICAL AND INDUSTRIAL SUPPORT	6
2. MUNITIONS PRODUCTION PROJECTS WHICH REACHED SERVICE STANDARDS OF QUALITY AND RELIABILITY	19
3. MUNITIONS PRODUCTION PROJECTS WHICH REACHED MASS PRODUCTION	20
4. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES FOR GUN PRODUCTION PROJECTS	22
5. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES FOR SMALL ARMS PRODUCTION PROJECTS	23
6. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES FOR COMPLETED AFV PRODUCTION PROJECTS	24
7. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES FOR ALL AFV PRODUCTION PROJECTS	26
8. AVERAGE NUMBER OF CRITICAL PATH DELAYS BY CATEGORY	28
9. TOTAL PRODUCTION DRAWINGS FOR MAJOR GUN AND AFV PROJECTS	31

LIST OF ANNEXES

- A. THE CORRELATION BETWEEN TIME LOST AND CRITICAL
 PATH DELAYS

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INTRODUCTION

Explanation of Terms

1. The indigenous manufacture of important munitions whether in peace or war, is dependent in some degree on locally held specialist technical knowledge of relevant military technologies, and on the existence of a well established industrial base. The latter does not itself convey the information and skill to make munitions, but provides the framework through which mass production of munitions can be developed, given the technical knowledge of the relevant military technologies.

2. Technical knowledge of the relevant military technologies consists of an understanding of two components:

- a. Developmental Design - the research and development which establishes the feasibility of achieving certain operational requirements for particular munitions.
- b. Manufacturing Design and Production Planning - the engineering which establishes the simplest design from which a munition can be mass produced, and the optimal layout for its production line.

3. The acquisition of such technical knowledge can be achieved by three methods:

- a. Original in-country Developmental Design, Manufacturing Design and Production Planning.
- b. Importation of overseas Developmental Designs, and Manufacturing Design and Production Planning.
- c. Modification of overseas Developmental Design, Manufacturing Design and Production Planning.

4. The instruments which allow the implementation of the first method are an established Research and Development (R and D) Capability for the relevant military technology, and an associated Specialized Production Capability.

5. An R and D capability consists of modern well equipped laboratories and testing facilities, with well trained scientists and engineers having extensive knowledge of the particular military technology. The concept of a dedicated R and D Capability is sufficiently flexible that it can refer to one self-contained research instrumentality, or to many separate establishments, scattered throughout government and private industry, whose sum total amounts to a balanced R and D Capability for a particular military technology.

6. An associated Specialized Production Capability consists of engineering workshops equipped comprehensively for the appropriate military technology. The staff consists principally of well trained and experienced engineers and draughtsmen with

extensive knowledge of most aspects of manufacture associated with the military technology. The concept of a Specialized Production Capability is as flexible as that for the R and D Capability, but usually consists of a single entity under government control; because many of the industrial processes and levels of precision engineering required for munitions are not usually performed or required in general industry. Apart from the above role, the Specialized Production Capability is also expected to act as an education centre for the rest of industry for its particular military technology, so that the necessary manufacturing techniques and production planning can be disseminated with the approach of war.

7. Original in-country Developmental Design, Manufacturing Design and Production Planning for the munitions of a particular military technology is often an extended and costly process, for which there is no absolute guarantee that viable or acceptable munitions will be the result. Developmental risks are high, as are Manufacturing Design risks. Major Powers are usually the main exponents of this method of acquiring technical understanding. This is because they have the resources to be able to accept the risks of failure; and also are the world's main arms dealers and so have a vested interest in developing new munitions from particular military technologies.

8. The second method of acquiring technical knowledge is often favoured by small powers. By accepting a significant degree of overseas technical support, the original Developmental and Manufacturing Design etc. can be followed closely, obviating largely the need for an R and D and Specialized Production Capability, and guaranteeing a high probability of success in local manufacture. The third method of acquiring technical knowledge (modifying overseas Developmental Design, Manufacturing Design and Production Planning) is also often favoured by small powers. By acquiring the details of a proven munition (i.e. one for which a successful Developmental Design exists as well as Manufacturing Design and Production Planning), a small power can modify such details to its own operational and industrial requirements, with an increased expectation of success than for original R and D and Manufacturing Design etc. Even though this method is simpler than the first, the technical problems are considerable, and require the existence of an appropriate R and D Capability for the military technology concerned, as well as an associated Specialized Production Capability. The reasons for this are examined below.

The Requirement to Modify Proven Munitions

9. Small powers often wish to modify the Developmental Designs of proven munitions of the major powers; despite the technical problems this often creates. A powerful reason for this is that the Defence Forces insist on their munitions performing reliably in their areas of prime operational importance; usually the land, sea and air environments inside and around national borders. However, since physical conditions (including weather and climate) can and frequently do vary widely from nation to nation, national Defence Forces often define different operational requirements for munitions.

10. Not surprisingly, such physical conditions can also stimulate the development of different tactical and strategic doctrines between the Defence Forces of different nations, although these developments are stimulated by other important factors as well (such as different weapons delivery systems). The existence of doctrines then help to define further necessary modifications to the Developmental Designs of munitions from the major powers so that the former can fit the new operational roles defined by small powers.

11. Small powers also often wish to modify the Manufacturing Design and Production Planning of proven munitions of the major powers. A main reason for this action is that the industrial base in small powers often lacks the range of manufacturing capabilities which are usually available to major powers for use in Manufacturing Design. Similarly, the level of precision engineering assumed in major power Manufacturing Design and Production Planning data is usually higher than that attained by the industry of small powers. Major powers use commonly many materials, specialized items of factory plant and machine tools, which small powers do not use frequently or do not even possess. Even industrial practice assumed in major power Manufacturing Design and Production Planning can differ significantly from that used in small powers.

12. Changes initiated, for any reason, to the Developmental Design of a proven munition will result in changes to the delicate balance between components and materials contained in the original Developmental Design. Often, the change in balance will be sufficient to produce a series of unintended interactions which change the operational performance of the munition in unacceptable ways. This chain-reaction is not easy to predict without considerable technical knowledge of the relevant military technology, and even harder to correct. An R and D Capability, such as already described, is required to control such a problem and to develop the technical solutions.

13. Similarly, an associated Specialized Production Capability is required to implement the modifications to the Manufacturing Design and Production Planning (of a proven munition) made necessary by the industrial limitations of small powers. This requires a sound understanding of all technical aspects of the original Manufacturing Design etc., and a comprehensive knowledge of the industrial resources and skills available within the small power, which could be utilized as substitutes for particular industrial processes.

14. Obviously, modifications to Developmental Design could in most circumstances be expected to produce changes in Manufacturing Design and Production Planning. However, in some circumstances, modifications to Manufacturing Design etc. dictated solely by industrial limitations (and not operational requirements) can have an effect on Developmental Design. For example, a small power may find it necessary to use a substitute material for a proven major power munition because it is cheaper, more readily available, and more familiar and easy to use by industry than the alternative used originally by the major power. Substitute materials have different chemical and physical properties (to their predecessor materials) which can often interact with the components and other materials in the munition in complicated ways, so altering the operational performance.

Derivation of Strategies of Technological and Industrial Support

15. Whenever a nation establishes an R and D Capability for a particular military technology and an associated Specialized Production Capability, it can be said that it is following the Strategy of Self Containment in munitions manufacture. This gives considerable technical flexibility, in modifying proven munitions from overseas which fall within the chosen military technology, and this can be developed further, if desired, into areas of original research. In any event, large amounts of technical information are generated in solving technical problems, and this can be used to trade with other nations for different technical data; thus providing a means of keeping informed of related technical developments around the world. With no information to trade, the only other way to gain important technical information from other nations is usually to buy it at an exorbitant price. This may not be necessary if a special relationship exists between two nations, but even such relationships can be strained if one party never has anything to contribute. However, the implementation of the Strategy of Self Containment gives the best of both worlds for it provides considerable independence of direct and continuous overseas support in a particular military technology - a circumstance of obvious importance when lines of communication to overseas sources of supply could be threatened - as well as technical data to trade with other nations.

16. Apart from Self Containment, there are other strategies of establishing indigenous munitions manufacture. The first is called the Strategy of In-Country Production Design. The circumstance in which it is applied occurs when a nation chooses to manufacture, for the first time, a proven munition which co-incidentally meets the levels of performance required by local operational conditions, and the tactical and strategic doctrine of the nation's Defence Forces. This would tend to obviate the need for an R and D Capability for the new military technology, as the Developmental Design would be acceptable as it stood. There would remain the need for the Specialized Production Capability so that the Manufacturing Design and Production Planning could be modified to suit local industry. (However, if the modifications to Manufacturing Design and Production Planning described in Paragraph 11 become complicated, there could be an adverse effect on Developmental Design as described in Paragraph 14, and this may well require an R and D Capability for further support).

17. The disadvantage of this Strategy is that Technical flexibility is restricted to Manufacturing Design and Production Planning. If the operational requirements of the munition are changed subsequently (a common occurrence), there is limited capability to modify the Developmental Design. Furthermore, Manufacturing Design can only be modified to the extent that such changes do not force changes to the Developmental Design.

18. The second is called the Strategy of In-Country R and D. The circumstance in which it is applied is when a nation has decided to manufacture a new munition for which the existing Manufacturing Design and Production Planning is easily implemented by local industry. This tends to remove largely the need for a Specialized Production Capability for the military technology concerned. There remains the need for an R and D Capability to modify the Developmental Design to achieve the different operational requirements desired by the Defence Forces of the nation.

19. The disadvantage of this Strategy is that technical flexibility is restricted largely to the ability to modify Developmental Design. Furthermore, the Developmental Design can only be modified to the extent that it does not cause changes to Manufacturing Design and Production Planning, otherwise there will be an increased need for an appropriate Specialized Production Capability.

20. The last strategy is called the Strategy of the Technology Package. The circumstances in which it is applied are when a nation has decided to manufacture a new munition for which the overseas Developmental Design, Manufacturing Design and Production Planning are all acceptable. An overseas Developmental Design becomes acceptable to the Defence Forces of a small power because it represents what was wanted in operational performance, or the armed services changed their operational requirements to fit the performance of the overseas Developmental Design. Overseas Manufacturing Design and Production Planning become acceptable to small powers because they are compatible with the capability of local industry, or because the small power is prepared to import particular components, factory plant and/or machine tools, which side step some of the industrial complexities. In one sense this is changing the capability of local industry to fit the Manufacturing Design and Production Planning of a major power. Since, in these solutions, the small power is not attempting to change Developmental Design or Manufacturing Design etc., there is little need for R and D and Specialized Production Capabilities for the particular military technology, except for minor testing and engineering tasks, which could be supplied probably without the need to establish such specialized instrumentalities.

21. The weakness of this Strategy is that there is very little technical flexibility associated with it. In periods of tension, it is not unusual for operational requirements for particular munitions to be changed progressively to counter enemy military capabilities. Similarly, available industrial capability is also restricted as more and more demands swamp capacity. The need in both instances to develop modified Developmental Designs and Manufacturing Designs etc. is clear, so that operational performance can be lifted, and available industrial resources used.

22. Table 1 summarises the relationship between the four strategies of technological and industrial support.

Table 1. THE RELATIONSHIP BETWEEN THE STRATEGIES OF TECHNOLOGICAL AND INDUSTRIAL SUPPORT

IMPACT OF DEFENCE FORCES
OPERATIONAL REQUIREMENTS
ON OVERSEAS DEVELOPMENTAL
DESIGNS OF MUNITIONS

Compatibility of Overseas Manufacturing Designs and Production Planning with Local Industry Capability		Modify overseas Develop- mental Design	Not Modify Overseas Develop- mental Design
	Modify Overseas Manufacturing Designs etc.	SELF CONTAINMENT	IN-COUNTRY PRODUCTION DESIGN
	Not Modify Overseas Manufacturing Designs etc.	IN-COUNTRY R AND D	TECHNOLOGY PACKAGE

INCREASING R AND D
MANUFACTURING DESIGN

The Impact of Time Constraints on Strategies

23. Sometimes, because of the pressure of imminent or actual war, governments and their armed services will alter their operational requirements for particular new categories of munitions, so that certain overseas designs for similar items become acceptable. In doing this, the armed services accept that the resulting munitions will not be as useful as they might have been if modified to accommodate local operational conditions and/or tactical and strategic doctrine; but the way is cleared quickly in a Developmental Design sense for the passage to Manufacturing Design and Production Planning. The requirement for an R and D Capability in this circumstance is theoretically minimal; but if one exists, it will allow the achievement of the original operational requirements on a gradual basis over time.

24. However, it is unlikely, for reasons stated already, that the Manufacturing Design and Production Planning of an overseas munition will prove compatible with the capability of the local industry of a small power. If no Specialized Production Capability exists, the problem is solved by importing the more difficult components, and bolstering local industry with specialized items of factory plant, machine tools and gauges from overseas. If an appropriate Specialized Production Capability exists, a modified form of the above can be adapted, while Manufacturing Design and Production Planning are modified progressively to suit local industry. In this way a short path is cleared for early local production, irrespective of which strategy is being used, provided there is no interference with sources of supply from overseas.

25. In wartime such sources can often be disrupted, despite the earnest desire of the suppliers to deliver their goods. This may occur, for example, from enemy action, or from new demands placed by the suppliers' own government. Faced with this situation, the usual response of engineers has been to attempt to improvise their way around the missing components, machine tools and factory plant etc.

26. In most instances this approach will probably succeed in producing timely and adequate munitions, if it can be assisted by appropriate R and D and Specialized Production Capabilities, so that Developmental Design and Manufacturing Design etc. can be altered for ease of local production, without too much further loss of operational performance in the munitions. In the absence of such capabilities, it is most unlikely that satisfactory solutions will be found which preserve the armed services' operational requirements. Indeed, great pressure will be applied to the armed services to lower such operational requirements even further to circumvent production problems. At this stage there is a high risk that in a race to save time, the required munitions will be degraded in their operational standards to the point of being ineffective in their contribution to military operations. At the same time they could be absorbing a disproportionate amount of productive resource which could be used more profitably elsewhere.

27. The strategy for which this scenario has most probability of occurring is the Strategy of the Technology Package. This strategy is followed by those of In-Country R and D, and Production Design, with the Strategy of Self Containment the least likely to be affected.

The Australian Experience

28. It is well known that during and after World War I, Australian Governments began to establish certain forms of munitions manufacture within Australia. This continued throughout the 1920s, and quickened in the 1930s with the steady emergence of the world crisis which became World War II. The Munitions Supply Board (MSB) guided most of the inter-war munitions development in Australia. The MSB concluded at its inception in 1921, that Australia did not have the resources for the original development of Developmental Design, Manufacturing Design and Production Planning for munitions. British (and later also, US) munitions were adopted mainly, and their Developmental Designs and Manufacturing Designs etc. were modified.

29. British munitions had been designed to operate in conditions very different from those which existed in and around Australia, although Australian tactical and strategic doctrine for the Defence Forces tended to be very similar to that of the British Defence Forces. Australian industry lacked the breadth and depth of British industry as reflected in Manufacturing Design etc. of British munitions, although it had developed well throughout the inter-war period. In addition, the manufacture of munitions introduced concepts of mass production and precision engineering which were entirely new to Australian industrial experience.

30. These were not the only problems. The Australian Defence Forces sought to preserve commonality of munitions and interchangeability of components with the British Defence Forces. This was because Australian forces were expected to operate as adjuncts to the British forces, so it made good sense to have common munitions etc. to reduce logistic support problems. However, this also imposed another strain on the modification of Developmental and Manufacturing Designs. Modifications prompted by unique operational requirements or limitations in industry pulled in one direction, while the need for commonality of munitions and interchangeability of components pulled in the other.

31. Shortly before World War II began, this problem was joined by another. As industrial capacity became more stretched under the growing weight of demands, pressure also mounted to develop significant commonality of components between different munitions in order to preserve what little industrial capacity still remained. Thus, for example, attempts were made to modify the Developmental and Manufacturing Designs of all guns made in Australia, so that they used standard wheels and many other similar components. This policy was even carried over into the aircraft industry. It introduced another requirement to modify British munitions which was tugging in its own direction away from all the others.

STRATEGIES OF TECHNOLOGICAL AND INDUSTRIAL SUPPORT FOR THE
AUSTRALIAN DEFENCE FORCES DURING WORLD WAR II

Introduction

32. The statement of the various strategies by which small powers can give technological and industrial support to their Defence Forces for war provides an analytical framework against which the experience of this problem by any small power can be examined. Australia is a typical small power in an industrial sense, and it is advantageous for a number of reasons to analyse her experience as an example. The Australian experience which is most relevant to this study is World War II, as this was the period of the most intensive munitions production programme ever launched in Australia. A large number of military technologies were involved. It is the aim of this part of the study to show which of the strategies were used by Australia for its greatest industrial endeavour in support of the armed services.

Strategy of Self Containment

33. The first strategy of Technological and Industrial Support to be followed in Australia as a matter of government policy was the Strategy of Self Containment, (referred to by successive Australian Governments as the Self Containment Policy). It began to emerge during World War I, and formed the functional basis of the Munitions Supply Board (MSB), which came into existence in 1921 under the Chairmanship of Mr A.E. Leighton. Drawing heavily on the wartime experiences of the British Ministry of Munitions, and under Leighton's prescient leadership, the MSB defined the problem of munitions production in Australia as being:

- a. the establishment of properly equipped Research Laboratories containing personnel with a sound knowledge of the current military technologies; and
- b. the establishment of limited, but specialized production units containing personnel with an understanding of advanced Manufacturing Design and Production Planning techniques for Mass Production.

34. Such capabilities were expected to exist as government instrumentalities, because Private Industry made little use of military technologies, and was unfamiliar with many of the common manufacturing skills associated with them. These instrumentalities were to form, according to the MSB, the nucleus of any future munitions production expansion. They would be able to modify overseas Developmental Designs to accommodate local operational and performance requirements, and adapt Manufacturing Design and Production Planning to emphasise Australian industrial strengths. They would also accept the responsibility for training Private Industry in the use of the more common military industrial processes, and in efficient Production Planning. In this way Private Industry would assume eventually the full weight of wartime Mass Production of munitions.

35. Throughout the period 1922-37, the MSB struggled with limited government funding to fulfill its objectives. In practice this forced it to concentrate on particular areas of military technology to the virtual exclusion of others. The technologies covered in this manner were:

- a. Guns,
- b. Small Arms,
- c. Explosives,
- d. Gun ammunition, and
- e. Small Arms ammunition.

36. It will be noted that the majority of these areas produced munitions which had high importance and high usage rates in wartime. The critical government R and D instrumentalities were the research sections of Munitions Supply Laboratories (MSL) which were:

- a. Explosives and Ammunition,
- b. Physics,
- c. Metrology,
- d. Metallurgy,
- e. General Chemistry,
- f. Chemical Defence,
- g. Technical Information, and
- h. Engineering.

Added to this was the Equipment Office which held all drawings and specifications of overseas munitions to be made in Australia.

37. The principal Specialized Production instrumentalities were:

- a. Ordnance Factory Maribyrnong,
- b. Small Arms Factory Lithgow,
- c. Explosives Factory Maribyrnong,
- d. Ammunition Factory Footscray (gun and small arms ammunitions sections), and
- e. Central Drawing Office.

38. The principal areas of military technology which were not covered properly by the MSB programme were:

- a. Optical Munitions,
- b. Radar and Electronic Components (not developed fully by any nation until the onset of the War),
- c. Military Frontline Aircraft, and
- d. Armoured Fighting Vehicles (AFV).

It had been the intention of the MSB to cover all of these areas (except Radar and Electronic components), but Government finance was not extended to establish such activities in the same manner as for Guns, Small Arms, Ammunition etc. Air Force and Army requirements for Aircraft and AFV respectively were expected to be very modest after 1922, and all of them were expected to be filled more easily from Britain than from costly local enterprises. No enthusiasm could be raised even to establish R and D capabilities.

39. In 1936 the Commonwealth Aircraft Corporation (CAC) was formed, with Government encouragement, by a number of commercial companies which eventually included such organisations as Broken Hill Proprietary Ltd., General Motors (Australia) and Imperial Chemical Industries. The objective behind CAC was to manufacture frontline military aircraft; but initially CAC settled on the production of an overseas training aircraft for its first project. The Company hoped that during the course of this effort, sufficient experience would be gained in Developmental Design, Manufacturing Design and Production Planning, to achieve its final goal within about five years (i.e. by 1941).

40. Much of CAC's preparatory work could have formed the basis of an established aeronautical R and D Capability and a Specialized Production Capability, yet when war began in September 1939, CAC's first aircraft (the Wirraway trainer) had been in Mass Production for only three months. This gave little time to complete the orderly and necessarily time consuming process of training staff and building up experience in Developmental Design, Manufacturing Design and Production Planning. Front-line military aircraft were several times more complex than training aircraft, and CAC was still, from its own estimates, several years away from achieving this end.

Strategy of In-Country Research and Development

41. The Strategy of In-Country R and D was not applied by Australian Governments. However, at least one important example existed in which an established R and D Capability was improvised during the War, and appropriate Manufacturing Design and Production Planning data was imported. The objective was the production of optical munitions in Australia. This example obviously resembled the application of the Strategy of In-Country R and D and so can provide some insight of what might have happened had the Australian Government chosen to apply it.

42. The first steps towards the production of optical munitions in Australia were taken by A.E. Leighton who had wanted to establish an optical industry in Australia. In 1918 he sent at least one officer to Britain for special training in the theory and practice of optical design. The Government economies of 1922-23 prevented an ambitious development of Leighton's plan, and only a small optical cell was set up in the MSL.

43. This was not a balanced R and D Capability as the restricted facilities and limited number of personnel prevented the development of broad experience and understanding of a representative range of optical research problems. Until June 1940 little interest was shown by the Defence Forces or the Government in making more finance available to correct this situation. For a number of reasons, it was more convenient to import all requirements of optical munitions from Britain. At the beginning of World War II Australia still made no crown glass or optical equipment, and even imported spectacle glass. No semblance of a Specialized Production Capability existed anywhere in Australia.

44. With the defeat of France in June 1940, all supply of military optical equipment from Britain was halted indefinitely, and no supplies were available from the USA to replace them. The Government turned to Britain and the USA for what amounted to a Technology Package. This was not possible to develop, as the specified materials and manufacturing equipment were not available, although in most cases the Developmental Designs and Manufacturing Designs were. This did not help much as the problem which then confronted the Australian Government was that this data had now to be modified to allow for the different properties of Australian materials, and for improvised methods of manufacture by whatever machine tools and plant could be put together from Australian and overseas sources.

45. Among other things, the Government needed the services of an appropriate R and D Capability. Fortunately, a well established R and D Capability was uncovered, although with the exception of the small MSL optics cell, it had not been created with the intention of aiding military optical research and manufacture. Commonwealth Solar Laboratories, sections of National Standards Laboratory, the physics departments of the Universities of Sydney, Melbourne, Adelaide and Tasmania, all combined their research experience and resources with MSL. In sum total, this amounted to a good grasp of the essential theory and practice of glass and optical instrument design. This had been acquired through the pursuit of the professional research interests of the various agencies.

46. It was not possible to improvise a Specialized Production Capability in the same way, for no manufacture of optical instruments took place in Australia so there was no appropriate factory plant etc. The Government had to obtain factory plant, machine tools and gauges from overseas when it could, and rely principally on the universities and assorted government laboratories (assisted by business executives), to improvise viable means of production.

47. The military technology area of Radar and Electronic Components followed a very similar pattern in Australia to that of Optical munitions. Because of this, it will not be addressed any further.

Strategy of In-Country Production Design

48. The Strategy of In-Country Production Design was not applied by Australian Governments. Nor do there appear to have been any examples (as for the Strategy of In-Country R and D), which represented circumstances similar to those described for the Strategy of In-Country Production Design.

Strategy of the Technology Package

49. The main areas in which the Australian Government applied the Strategy of the Technology Package were Frontline Military Aircraft construction, and the manufacture of AFV.

50. The attempt to manufacture frontline military aircraft began seriously in Australia in 1937 at CAC. However, by early 1939 the Australian Government realised that the CAC project was not likely to succeed until at least 1941, and that Australia could be at war well before this date. Aware of the grave shortage of frontline military aircraft throughout the Empire, and under prompting from the British, the Australian Government decided to build frontline military aircraft in Australia according to the Strategy of the Technology Package.

51. The Government Aircraft Factory (GAF) was created in July 1939 to assemble Beaufort Bombers. The most important components such as engines, propellers, gun-turrets, light alloy parts, aircraft instruments, undercarriages etc., were to be imported from Britain, and the rest made in Australia. The project was to have full support from Britain, which would supply all Developmental Design and Manufacturing Design data, plus any other technical support discovered to be necessary. Australians would be trained in Britain, and necessary factory plant, jigs and machine tools would be despatched to Australia. The first aircraft were expected to be produced in 1940. The project was necessarily heavily reliant on British support even for materials; and the intention was to build an aircraft as closely similar as possible to the British originals.

52. The Government also established, under the Council of Scientific and Industrial Research, the Aeronautical and Engine Testing Research Laboratory in August 1939. Its main functions were to assist the Air Force and industry in problems with manufacture and operation of aircraft, and to undertake the long range research on fundamental problems of aeronautics on which future progress of the aircraft industry would depend. The Laboratory thus combined the basic requirements for an established R and D Capability and a Specialized Production Capability. Unfortunately it was not fully operational until the end of 1941, and had little experience in manufacturing problems. In the meantime, the Government had to continue to support CAC in its attempt to design frontline aircraft from a very narrow base of R and D and production experience; and to put its main effort into the GAF Technology Package project, in the hope that the production of frontline military aircraft in Australia might be achieved at an early date.

53. The production of AFV in Australia was not attempted seriously until December 1938 when the Machine Gun Carrier LPl entered Quantity Production. This was the simplest AFV then made in Britain, and bore little resemblance to the more advanced AFV of World War Two. The project was based heavily on British support, and did not represent the beginning of a systematic examination of AFV production in Australia. The Australian Army did not, at this time, put much emphasis on armoured warfare, and did not argue energetically for the development of an established R and D Capability and Specialized Production Capability. As the Army's demands for such vehicles were relatively low, it looked to Britain to supply its requirements.

54. The Army changed its philosophy during May/June 1940, largely as a consequence of the Allied defeat in France by German Panzer Divisions, and the ensuing collapse of British Empire Supply. A flood of large orders for the full range of AFV including medium and heavy tanks, cascaded on the Department of Munitions.

55. Superficially, Australia looked equipped to produce AFV, for it had a well established heavy industry, and also had major international car companies, such as General Motors and Ford, located in-country. However, while being in command of a wide range of industrial skills in comparison to the rest of Private Industry, the Car Companies still essentially assembled their vehicles around the more complex subassemblies which were imported. As of June 1940, Australia was still to mass produce its first complete locally-made automobile.

56. Because there were no R and D or Specialized Production Capabilities for AFV in Australia, the Department of Munitions and the Army decided to follow overseas designs closely, to the extent of importing not only all relevant Developmental Designs, Manufacturing Designs and Production Planning data, but also a large body of machine tools and gauges, many items of factory plant and major components such as engines. The main source of this material was to be the USA, and the tanks were to be almost direct copies of the US M3, and later the M4. The desire to incorporate local modifications was to be resisted. This Technology Package Strategy was approved by the Australian Government.

57. The Department of Munitions also decided in October 1940 to create the AFV Design and Development Section at Fishermans Bend Victoria. This was the closest Australia got to an established R and D and Specialized Production Capability for AFV. It was strictly limited by the level of the training its personnel had received, and was actually a final assembly and test centre for more or less completed AFV.

MEASUREMENT OF EFFECTIVENESS

Introduction

58. While it can be shown that various strategies of technological and industrial support were employed in Australia during World War II, it also needs to be established whether they were successful in their primary task, i.e. the timely supply to the Defence Forces of Munitions of sufficient quality and quantity. Until this matter is resolved it will be difficult to determine which strategies were practical options and why some apparently failed. The method by which the effectiveness of each strategy is established is now described.

59. The activities of each technological area in Australia during World War II were channelled into production projects designed to manufacture the various munitions associated with the military technology. The Defence Forces judged the effectiveness of such projects according to the following criteria:

- a. Munition projects were to be capable of producing munitions to the standards of Quality and Reliability (i.e. to the operational requirements) determined by the relevant Service as necessary to ensure adequate role fulfillment and survivability against competing enemy munitions;
- b. such munitions were to be capable of being Mass Produced by Australian (Government or Private) Industry; and
- c. mass production of munitions was to be achieved in Time for the Defence Forces to receive significant quantities before or during the period of greatest military utility.

Quality and Reliability

60. The concept of Quality and Reliability was defined as the series of physical and chemical parameters which described the nature and operational performance of the munition desired by the Defence Forces. These parameters were initially outlined in general terms in Defence Force operational requirements, but defined much more closely with the successful completion of a Developmental Design. Inspection procedures were derived from this data; and a munition was judged to have attained the requisite levels of Quality and Reliability when it passed all Inspection tests and was accepted by the Defence Forces.

61. The concepts of Quality and Reliability adopted by the Australian Defence Forces for particular munitions had not been derived independently, but rested primarily on British concepts and experience. There were good reasons for this:

- a. Australian forces were conceived as operating as adjuncts to the British Defence Forces, in which case it made good sense to:
 - (1) have standard munitions with interchangeability of components and stores in order to reduce logistic support problems; and
 - (2) that Australia should accept the major partner's munitions as the standard;
- b. the British Defence Forces had more experience in defining the operational mission for a munition, and its minimum level of survivability; and
- c. British R and D supporting munition definition was thought to be generally very sound, resulting in munitions which were at least as effective and consistent as those designed elsewhere in the world.

62. The technical information which defined the British concepts of Quality and Reliability for a particular munition was presented in the relevant Process Specification, and Inspection Procedure. The Process Specification contained the Developmental Design drawings outlining the components, materials and tolerances required; and the Manufacturing Design and Production Planning. Inspection Procedure outlined the gauges to be used, and the physical and chemical parameters to be checked at various stages of the production process.

Mass Production

63. The Production authorities and the Australian Defence Forces considered that the Mass Production of a munition had been achieved when the first complete unit had been produced to Defence Force standards (of Quality and Reliability) by production line methods (sometimes referred to as Quantity Production).

64. The desire of the Australian Defence Forces for the Mass Production of most of the munitions they required, was related to their awareness that this was the only method by which the volume of units produced could match, eventually, the demand created by expanding forces and war usage. Batch production¹, and Toolroom production² methods were often more convenient, but could rarely achieve the volume of units required for particular munitions.

65. A munition had to be specially adapted if it was to be mass produced successfully, whereas this was not necessarily true for Batch or Toolroom production. This meant that after a munition had been designed and developed to achieve the Defence Forces standard of Quality and Reliability, a new process was superimposed - Manufacturing Design. The latter aimed, among other things, to achieve:

- a. Identification of the areas of fine tolerance, i.e. critical manufacturing points;
- b. reduction in the number of complicated manufacturing processes;
- c. reduction in the total number of components; and
- d. standardisation of components with other munitions.

66. Manufacturing Design information was contained as part of the Process Specifications, which came mainly from Britain, but also from the USA.

- Notes. 1. Batch Production - the division of the production cycle for a particular product into a number of phases for which the main production line is rearranged each time (i.e. there is no continuous production cycle). Batch Production is particularly useful when insufficient factory plant and machine tools are available. In this situation maximum use is made of what is available by redeploying the scarce items at each new phase of the production cycle into different places of the new production line.
2. Toolroom Production - the assembly of production units without a central production line (i.e. rather than bring the semi-completed product to where components, sub-assemblies, skilled workers and their tools are positioned as by a production line, Toolroom Production brings the components and workers etc. to the semi-completed production unit which is positioned permanently at some central geographic location such as a toolroom).

67. The final stage in the preparation of a munition for Mass Production was the Production Planning; which entailed the design of the production line and factory layout, together with the correct positioning of testing and inspection stations. British (and US) Process Specifications contained most of this data; but if the Manufacturing Design had been changed by Australia, revisions to the original Production Planning were also required. Sometimes Production Planning had to be changed even if the British (and US) Manufacturing Design remained intact. This was usually related to the lack of particular types of machine tools which had to be replaced by some substitute.

Timeliness

68. The achievement of Mass Production was not much use if it occurred after the time of the munition's greatest usefulness to the Defence Forces. The Timeliness of Mass Production therefore became a most important criterion of the effectiveness of the wartime production effort.

69. When the Mass Production of a new munition was contemplated, the relevant Defence Force would consult with the Production authorities to define a production schedule. This was determined on the basis of a compromise between the period of time during which the Defence Force thought it would urgently require the munition, and the earliest time the Production authorities could begin mass production. If the latter fell within the broad period of time nominated by the Defence Force, the decision to proceed with manufacture was taken usually, and a Production schedule finalised.

70. A good means of measuring the Timeliness of production projects in reaching Mass Production is to compare Production Schedule Lead Time with Actual Production Lead Time. The latter was always greater than the former, so the difference between them gives the Time Lost. The expression of Time Lost as a percentage of Production Schedule Lead Time, gives a satisfactory measure of the Timeliness of production projects. Projects which had small percentages are likely to have fallen within the period of most operational usefulness for the Defence Forces. Projects with large percentages obviously faced a higher probability of being overtaken by events, and hence being cancelled by the Defence Forces.

Application of Measures of Effectiveness

71. It is intended to apply the three measures of effectiveness (i.e. Quality and Reliability, Mass Production, and Timeliness), to the different areas of military technology present in Australia during World War II, in order to determine their relative success in meeting Defence Force standards. It is then intended to see whether there is a correlation between levels of success or failure associated with each military technology, and the various strategies of technological and industrial support.

RESULTS

The Scope of Research and Analysis

72. The ideal approach to the study of the success of particular military technologies would be to apply the measures of effectiveness to every production project associated with a particular military technology. This is an impossibly large task; and so the detailed application will be restricted to three areas of military technology, and the balance will be addressed generally. The three areas are the Gun production projects, Small Arms production projects and the AFV production projects. The first two are associated with the Strategy of Self Containment, and the last with the Strategy of the Technology Package. For the reasons outlined in Paragraph 32, the period under study is World War II.

Success in Quality and Reliability

73. Table 2 indicates the number of Gun, Small Arms and AFV production projects which attained the required Defence Force standards of Quality and Reliability in the munitions they produced. This data and that following are drawn largely from CSE Report 13 (Reference 1).

Table 2. MUNITIONS PRODUCTION PROJECTS WHICH REACHED SERVICE STANDARDS OF QUALITY AND RELIABILITY

MUNITIONS TECHNOLOGY	TOTAL NUMBER OF PRODUCTION PROJECTS	PROJECTS ATTAINING THE STANDARD OF QUALITY AND RELIABILITY
GUN	14	14
SMALL ARMS	9	9
AFV	11	6

74. It should be noted that Production Projects refer to activities which aimed at making more or less complete munitions, and not to those projects which made essentially components.

75. It is clear from Table 2, that with all Gun and Small Small Arms production projects achieving the required Defence Force standards of Quality and Reliability, these areas of military technology were successful in meeting the first measure of effectiveness.

76. By contrast, with only 6 out of 11 AFV production projects reaching the required standards of Quality and Reliability, the AFV area of military technology was ineffective. Furthermore, for five of the six successful AFV projects, the standards of Quality and Reliability had been dropped significantly. The Australian Government was unable to import key items of factory plant, machine

tools, jigs and major components; which prevented Australian engineers from implementing the British and US Manufacturing Designs and Production Planning. Modifications were introduced in an attempt to still realise the original operational requirements by using different manufacturing processes and different components which could be produced in Australia. This had an influence on Development Design and took Australian engineers back into many fundamental problems of AFV development which had been solved effectively in the overseas Developmental Designs. As the engineering problems became more acute, the Australian Army had little choice in many instances than to abandon the original operational requirements, and to establish new ones set at a somewhat lower level. The alternative was the prospect of no mass production of AFV for many months.

77. The result of these actions was that the AFV Production Directorate of the Department of Munitions was now able to manufacture many of the required AFV, but it still failed to produce acceptable tanks. After the war, the Master General of the Ordnance stated officially that only one AFV production project had been really satisfactory in terms of Quality and Reliability, and this had been the Machine Gun Carrier LP2, LP3 etc. (i.e. the following Marks to the LP1). It is noteworthy that the Machine Gun Carrier was the simplest AFV made in Australia during the war.

Success in Mass Production

78. Table 3 indicates the number of Gun, Small Arms and AFV production projects which succeeded in mass producing munitions to the Defence Forces standards of Quality and Reliability.

Table 3. MUNITIONS PRODUCTION PROJECTS WHICH REACHED MASS PRODUCTION

MUNITIONS TECHNOLOGY	TOTAL NUMBER OF PRODUCTION PROJECTS	PROJECTS REACHING MASS PRODUCTION
GUN ¹	14	11
SMALL ARMS ¹	9	7
AFV ¹	11	6

Note. 1. Individual projects are listed in Tables 4, 5 and 7.

79. Of the 14 Gun projects, three were designed for Batch or Tool Room Production. The remaining 11 projects all reached mass production.

80. Small Arms production projects also succeeded except for two projects, one of which never enjoyed high priority, but was somewhat unrealistically planned to reach Mass Production; and the second was never planned to reach Mass Production, but was operated deliberately on the Batch Production method.

81. AFV production projects were once again largely unsuccessful, only six out of 11 reaching Mass Production. It will be remembered that the standards of Quality and Reliability had been lowered (thus, among other things, easing the difficulty of Mass Production) for five out of these six projects, the exception being the Machine Gun Carrier LP2, LP3 etc. Apart from being the simplest AFV to be made in Australia, this was also the only AFV project to be mass produced before the war in its original Mark (the LP1), so that there was some directly relevant experience to be utilised for the LP2 and the LP3.

82. The most important AFV project, the AC1 Tank, failed to reach Mass Production according to the definition of the term used in this study (see Paragraph 63). It was not accepted by the Army during the War for it failed to pass even the reduced standards of Quality and Reliability which the Army had adopted. Notwithstanding this, the AC1 was allowed to be manufactured by production line methods on the promise that the AFV Production Directorate of the Department of Munitions could recycle the first tanks and succeed in passing the required inspection tests. The Directorate failed; and production was ceased after 66 AC1 had been manufactured.

Timeliness of Mass Production

83. Table 4 indicates the extent to which the Gun production projects conducted in Australia over-ran their Production Schedule lead times for reaching Mass Production. Those projects which were never intended in their planning to reach Mass Production are excluded.

84. Gun production projects overran their Production Schedule lead times for Mass Production by an average of 29%. Thus, despite the support of established R and D and Specialized Production Capabilities, and allowance by engineering staff for the obvious wartime delays and obstructions, critical path delays still occurred, and caused overruns of agreed production time scales. It will be seen shortly, that the time lost was not unusual. It did not apparently upset Defence Force concepts of Timeliness significantly, for all projects were allowed to reach Mass Production even though they had overrun Production Schedule lead times; and they continued in production for many months afterwards. All of this would have been inconsistent if a project was producing a munition which was no longer important and vital.

85. Table 5 indicates the extent to which the Small Arms production projects conducted in Australia overran their Production Schedule lead times for reaching Mass Production. Those projects which were never intended in their planning to reach Mass Production are excluded.

Table 4. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES
FOR GUN PRODUCTION PROJECTS

GUN PROJECTS	ACTUAL PRODUCTION LEAD TIME (Months)	PRODUCTION SCHEDULE LEAD TIME (Months)	TIME LOST (Months)	TIME LOST AS PERCENTAGE OF SCHEDULED LEAD TIME
3.7" AA Gun	32	?	?	?
3" Mortar	18	15	3	20
2 Pdr AT Gun	14	9	5	55.5
25 Pdr Field Gun	26	18	8	44.4
40mm Bofors	30	27	3	11.1
6 Pdr AT Gun	15	12	3	25
2" Mortar	13	9.5	3.5	36.8
4" Mk XIX Naval Gun	16	?	?	?
17 Pdr AT Gun	16	13	3	23
4.2" Mortar	7	6	1	16.6
25 Pdr Pack Howitzer	15	12	3	25
AVERAGE	17	13.5	3.6	29%

Table 5. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES
FOR SMALL ARMS PRODUCTION PROJECTS

SMALL ARMS PROJECTS	ACTUAL PRODUCTION LEAD TIME (Months)	PRODUCTION SCHEDULE LEAD TIME (Months)	TIME LOST (Months)	TIME LOST AS PERCENTAGE OF SCHEDULED LEAD TIME
0.303 Rifle	?	?	?	?
Vickers Mk1 Machine Gun	?	?	?	?
Bren Gun	28	23	5	21
0.38" Revolver	No Mass Production			
Owen Submachine Gun	19	12	7	58
Hispano 20mm Aircraft Cannon	17	14	3	21
Austen Submachine Gun	7	5	2	40
Polsten 20mm Machine Gun	24	19	5	26
AVERAGE	19	14.6	4.4	33%

86. Small Arms production projects overran their Production Schedule lead times for Mass Production by an average of 33%. This happened despite the existence of established R and D and Specialized Production Capabilities, and allowance by engineering staff for the obvious wartime delays and obstructions. Given the small size of the two complete populations of data, the difference in percentage time lost between Gun projects and Small Arms projects is probably not significant. The time lost for Small Arms projects did not apparently upset Defence Force concepts of Timeliness for all projects (excepting the 0.38" Revolver) were allowed to reach Mass Production even though they had overrun their Production Schedule lead times; and they continued in production for many months afterwards. The 0.38" Revolver project had very low priority, whereas all other Small Arms projects were in the top bands of priority rating in Australia: the project was cancelled before it reached Mass Production.

87. Table 6 indicates the extent to which the AFV production projects in Australia overran their Production Schedule lead times for reaching Mass Production. Those projects which were never intended in their planning to reach Mass Production are excluded, as are those five projects which were cancelled by the Army before they could reach this stage of production.

Table 6. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES
FOR COMPLETED AFV PRODUCTION PROJECTS

AFV PROJECTS	ACTUAL PRODUCTION LEAD TIME (Months)	PRODUCTION SCHEDULE LEAD TIME (Months)	TIME LOST (Months)	TIME LOST AS PERCENTAGE OF SCHEDULED LEAD TIME
Machine Gun Carrier LP1	22	?	?	?
Machine Gun Carrier LP2, LP3 etc.	10	8	2	25
2 Pdr AT Gun Carrier	13	10	3	30
Scout Car	11	9	2	22
Light Armoured Car	8	7	1	14
3" Mortar Carrier	8	7.25	0.75	10
AVERAGE	12	8.25	1.85	20%

88. Apart from noting that AFV production projects overran their Production Schedule lead times for Mass Production by an average of 20%, the important point is that this was much less than for Small Arms or Gun production projects. Yet this result should have been reversed, for AFV production projects had no established R and D and Specialized Production Capabilities to support them, whereas Gun and Small Arms production projects had such support. The AFV production projects, according to the hypothesis of this study, should have overrun their Production Schedule lead times for Mass Production by a much greater margin than did the Gun and Small Arms projects.

89. However, closer examination of of AFV production project data reveals that only five projects had complete information (because, with one exception, all other projects failed to reach Mass Production); and four of these were amongst the five projects which had their standards of Quality and Reliability lowered below what the Army regarded as satisfactory. These inferior AFV consequently became easier to Mass Produce, allowing their Actual Production lead times to conform closely to their Production Schedule lead times. In this sense they were received by the Army within the time span of their greatest utility, but did not represent what the Army really needed.

90. A more realistic image of the AFV technology area is gained when some consideration is made of the production projects which failed to reach Mass Production. Unlike the 0.38" Revolver project, of the Small Arms group, all of the AFV production projects which were in this category were in the top band of priority in Australia. The tank projects were listed by the Army as the most

important over all other activities in every other category of military equipment. No effort was spared to achieve Mass Production within a useful time; but in the end, the Army was compelled to cancel them all, as they either could not reach satisfactory standards of Quality and Reliability, or could not be Mass Produced in their desired form within such time that they could still assist significantly the operational situation. More satisfactory alternatives were sometimes available from overseas, or the strategic situation obviated the need for such AFV. In this regard it is interesting to restate Table 6 (Table 7) with the lead times expended on those projects which failed to reach Mass Production.

91. The overrun of Production Schedule lead time is higher than before, and similar to that from Small Arms. However most of the AFV projects which failed to reach Mass Production were not within reach of this stage, and would have needed much more time, had they not been cancelled by the Army. The Percentage Time Lost for AFV would probably have been twice that for Small Arms projects before Mass Production could have been achieved.

Summary of the Gun, Small Arms and AFV Production Projects

92. These results show that the military technologies of Guns and Small Arms enjoyed almost uniform success according to the criteria of Quality and Reliability, Mass Production, and Timeliness. By contrast, AFV military technology enjoyed at best indifferent success, or at worst almost total failure, with only one project out of 11 attaining all three criteria of success (the Machine Gun Carrier LP2, LP3 etc.).

93. It is easy to associate the success of the Gun and Small Arms technological areas with the development of appropriate established R and D Capabilities at the Munitions Supply Laboratories, and with the existence of associated Specialized Production Capabilities at Ordnance Factory Maribyrnong and Lithgow respectively. The AFV technological area had none of these at the beginning of the War. In the circumstances, the most probable road to success for AFV was through the Strategy of the Technology Package. This route was blocked effectively when the Australian Government was unable to import many of the critical items of factory plant, machine tools and components that it wanted. The attempts to improvise around the bottlenecks drew Australian engineers into the realms of significant modification of both Developmental and Manufacturing Designs without the existence of R and D and Specialized Production Capabilities to guide them. The creation of the AFV Design and Development Section after 13 months of war was a belated realisation of at least part of this problem. The Section never had time to become established properly before it was virtually closed down when the AFV Production Directorate was abolished in October 1943.

94. The consequence of these deficiencies was that AFV projects were often unable to realise the operational requirements laid down for them by the Army. The attempts to improvise unleashed complicated and uncontrolled changes to the operational performance of many of the AFV. Prolonged attempts to solve these without the expert assistance of R and D and Specialized Production Capabilities also often resulted in AFV projects not reaching Mass Production in time to still be useful to the Army.

Table 7. PRODUCTION SCHEDULE AND ACTUAL PRODUCTION LEAD TIMES
FOR ALL AFV PRODUCTION PROJECTS

AFV PROJECTS	ACTUAL PRODUCTION LEAD TIME (Months)	PRODUCTION SCHEDULE LEAD TIME (Months)	TIME LOST (Months)	TIME LOST AS PERCENTAGE OF SCHEDULED LEAD TIME
Machine Gun Carrier LP1	22	?	?	?
AC1 Tank ¹	27	19	8	42
Machine Gun Carrier LP2, LP3 etc.	10	8	2	25
AC2 Tank ¹	7	6	1	17
2 Pdr AT Gun Carrier	13	10	3	30
Scout Car	11	9	2	22
Light Armoured Car	8	7	1	14
Heavy Armoured Car ¹	17	9	8	89
AC3 Tank ¹	21	14	7	50
3" Mortar Carrier	8	7.25	0.75	10
AC4 Tank ¹	16	?	?	?
AVERAGE	14.5	9.9	3.6	33%

Note: 1. Projects which were cancelled before reaching Mass
Production

95. However, even though this attempt to implement the Strategy of the Technology Package was a general failure (largely because of the intercession of external factors interfering with supply of the necessary key items of factory plant etc.), the strategy did succeed in producing an assured supply of some AFV for the Army. Even though these vehicles were inferior to what was desired, they were better than nothing; especially when the Australian Government was having difficulty in importing any AFV from overseas, and the Japanese looked as though they would land in Australia. In this context the production, for example, of the 66 substandard AC1 Tanks was nevertheless an important achievement.

Significance of Critical Path Delays

96. Critical path delays are the types of major disruption which affected production projects during the War. The explanation adopted for the failure of the AFV and the success of the Gun and Small Arms projects in fact predicts a particular pattern of critical path delays. By comparing this predicted pattern with the actual pattern of critical path delays, a test has been constructed for validity of the central explanation.

97. Critical path delays fell into five categories:

- a. Slow delivery from overseas of technical data and standardised plans and drawings;
- b. Slow delivery from overseas of components;
- c. Administrative delays;
- d. Machine Tool shortages; and
- e. Technical delays.

98. The time lost by production projects to reach Mass Production is highly correlated with the number of critical path delays and has the following relationship:

$$y = 1.04x - 0.04$$

where y = Number of critical path delays

x = Time lost (Production Schedule lead time subtracted from Actual Production lead time) in months.

The data on which this relationship is based, and the associated statistics are at Annex A.

99. The relationship shows that time lost per critical path delay was about one month. Thus if critical path delays are broken down into categories, and expressed as averages for the number of projects in a technology area (i.e. Gun, Small Arms and AFV), they will indicate accurately the prime areas of disruption.

100. It has been shown that the failure of AFV projects can be traced to the inability of the Australian Government to implement the Strategy of the Technology Package; and then to the absence of

established R and D, and Specialized Production Capabilities to support the departures from British and US Developmental and Manufacturing Designs. In these circumstances such departures promised a high level of technical disruption within AFV projects. Indeed, for the preceding argument to be completely correct, the highest average critical path delay for AFV projects should be for the category of Technical delays. Furthermore, this average should be significantly higher than for the corresponding average Technical delays for Gun or Small Arms projects, for the latter had the assistance of R and D and Specialized Production Capabilities. If other categories of average critical path delay are higher for AFV than for the same categories for Gun or Small Arms projects, then this will suggest that other factors are prominent in explaining the AFV failure as well as those already indicated. In this sense, the study of the pattern of critical path delays acts as a test of the validity of the central explanations advanced for the failure of the AFV projects.

101. Average critical path delays by category for all Gun, Small Arms and AFV projects are presented in Table 8.

Table 8. AVERAGE NUMBER OF CRITICAL PATH DELAYS BY CATEGORY¹

MILITARY TECHNOLOGY	SLOW DELIVERY PLANS/DRAWINGS FROM OVERSEAS	SLOW DELIVERY OF COMPONENTS FROM OVERSEAS	ADMIN DELAYS	SHORTAGES IN MACHINE TOOLS	TECHNICAL DELAYS
GUNS	0.6	0.1	1.0	1.0	0.6
SMALL ARMS	0.4	0.0	1.4	0.9	0.62
AFV	0.1	0.5	1.2	0.3	1.6

Note. 1. These figures approximate average delays in months (see Paragraph 99).

2. Allowance has been made for the distorting effect of the Owen gun project for which there were two totally avoidable technical delays which were caused by certain groups attempting to halt the project - see CSE Report 13 Owen Gun Project.

102. The first thing to notice from Table 8 is that the average Technical delay for AFV projects is noticeably larger than any other entry for AFV. This means that the first condition of the test has been met. It is also obvious that the second condition has been met, because the average technical delay for AFV projects is over twice the average for either Gun or Small Arms projects. The results for the other categories of delay are now explained in turn.

103. Slow Delivery of Plans/Drawings etc. The important fact to note from this category is that AFV suffered smaller average delays than either Guns or Small Arms. The reason for this was that the Gun and Small Arms technology groups were striving where possible for a very high degree of commonality in components with

Britain, which made them reliant to some degree on the prompt arrival from overseas of changes initiated by the British Defence Forces to previously agreed standard designs. The AFV group did not attempt to achieve the same level with either Britain or the USA, and so was less dependent on prompt receipt of relevant information from overseas.

104. Slow Delivery of Components etc. The average critical path delays for the next category indicate that AFV projects suffered more than either Gun or Small Arms. The explanation is that production authorities, when faced by the prospect of increasingly serious technical delays, attempted to alleviate some of the pressure on their limited technical resources by importing certain proven, but readily available components. This allowed technical resources to be deployed on the unavoidable problems. Unfortunately, this introduced a new area of disruption as these components often did not arrive on time. Gun and Small Arms were barely reliant on any overseas components at all. Thus, this category of delay was related to the problem of technical delay and probably does not indicate an important new factor.

105. Administrative Delays. The average critical path delays for the third category are broadly similar for all three technology areas. The figure for Small Arms would be 1.1 except for the influence of the Owen gun project. This project suffered from a series of deliberately initiated disruptions, and in this respect does not conform to the pattern for all other projects (see Reference 1, Annex A, Appendix 17 - The Owen Sub-Machinegun Project).

106. Shortages in Machine Tools. The fourth category is notable for the average AFV critical path delay is much less than for either Guns or Small Arms. AFV projects suffered little from machine tool shortages because most of the projects flowed on sequentially, with the contractors retaining most of their machine tools for the next AFV project. By contrast, Gun and, to a lesser degree, Small Arms projects tended to be conducted concurrently, and over longer periods of time as production runs were extended. This did not allow much transfer of machine tools between projects, and helped to create shortages as old projects continued in production, while new ones were added.

107. This means that the last condition of the test has been met, for no new factors have been identified by this method which could lead to the modification of the explanation of the AFV failure and the Gun and Small Arms success. In other words, there is no internal inconsistency in the explanation. However, there remains a possible external inconsistency which is related to the question of complexity.

The Influence of Munition Complexity

108. It could be argued that the inability to achieve Defence Force standards of Quality and Reliability and Timely Mass Production was a function of the complexity of the munitions and military technology, and not of the application of a strategy of technological and industrial support. Thus, as the munitions became more complex, technical delays became more numerous, and Australian engineers found it more difficult to achieve the Defence Force standards.

109. The common understanding of complexity in armament is the number of discrete industrial operations needed to manufacture a particular munition. On this basis, the Gun projects undertaken during World War Two in Australia should have suffered as much failure as the Australian AFV projects for they were of equivalent complexity. Normally AFV would have been considerably more complex; but Australian engineers attempted to reduce the number of industrial operations by importing as many components as were practicable. This saved Australian industrial resources, and reduced complexity. The best indication of this was the number of Production Drawings for each AFV and Gun (see Reference 1, p. 19). Some comparative data is presented in Table 9.

110. Of course, Gun projects were much more successful than AFV in reaching the Defence Forces standards. This means that, in this case at least, complexity (as understood commonly) was not a decisive factor in explaining the failure of the AFV projects.

111. Similar comparison can be made between the AFV technological area and that of frontline aircraft production. The main area for this endeavour was the GAF Beaufort Bomber and Beaufighter projects. Both aeroplanes had over 8000 Production Drawings, and so were considerably more complex than the most complicated AFV project (the ACI Tank) which had 3349. Both GAF projects succeeded in reaching all Defence Force standards in less time than the major AFV tank projects that had been operating. The main reason for this result was that, in comparison to the AFV area, GAF followed the Strategy of the Technology Package much more closely and resisted the desire to introduce significant modifications and so drift into the Strategy of Self Containment without the requisite R and D and Specialized Production Capabilities. When it faced serious developmental weaknesses in the Beaufort Bomber design, it stuck closely to the British solutions, for Britain had identified basically the same weaknesses, and had an infinitely more experienced R and D Capability and Specialized Production Capability than Australia for this technological area.

112. These results show that rising complexity did not necessarily lead to more technical disruption for munitions projects.

113. However, complexity can also be related to lack of knowledge on how a munition is designed and made. In this sense a munition becomes very complex to manufacture even though it may, in fact, have only a few industrial operations associated with it.

Table 9. TOTAL PRODUCTION DRAWINGS FOR MAJOR GUN AND AFV PROJECTS

	NUMBER OF PRODUCTION DRAWINGS
<u>GUNS</u>	
3" Mortar	134
4.2" Mortar	168
25 Pdr Pack Howitzer	580
6 Pdr Anti Tank Gun	590
2 Pdr Anti Tank Gun	717
17 Pdr Anti Tank Gun	860
25 Pdr Field Gun	1416
40mm Bofors AA Gun	1973
3.7" AA Gun	2831
<u>AFV</u>	
3" Mortar Carrier	634
Machine Gun Carrier LP2, LP3	895
Scout Car	1152
2 Pdr Anti Tank Gun Carrier	1289
AC1 Tank	3349

114. With the exception of the Owen gun, virtually all munitions used in Australia were based on British and US munitions; and the Australian Government had access to all relevant Developmental Design, Manufacturing Design and Production Planning data on these munitions.

115. If the Strategy of the Technology Package was followed correctly for a particular military technology, the British and/or US data was directly relevant to the production of the associated munitions in Australia, i.e. there was no lack of knowledge in Australia. However, if the British/US Manufacturing Design or Developmental Design was modified to some degree, as often happened under the Strategies of Self Containment or In-Country R and D, much of the British and US data became irrelevant. Attempts to alter a proven munition often unleashed a series of unintended changes to the munitions operational performance.

116. These were controllable if appropriate R and D Capabilities and Specialized Production Capabilities existed. They were not if the Strategy of the Technology Package was misapplied, severing the reliance on British and US data. When this situation occurred, a considerable lack of knowledge was introduced, which had the effect of increasing greatly the complexity of a munition, beyond the number of industrial operations which had to be performed normally for its completion. In these circumstances, munitions often did have difficulty in reaching Defence Force standards. Thus, in at least one sense, complexity was linked to the strategies of technological and industrial support.

117. This is not to say that complexity as measured by the number of industrial operations had no influence on the munitions production effort. The completion of a complicated munition required many industrial operations, and so could be expected to take more time than that of a simple munition. Thus it can be argued that the more complex a munition became, the longer the lead time for its completion. Data contained at Annex E of Reference 1 shows that this relationship did, in fact, exist during World War Two. Good linear correlations were established whenever data on the number of production drawings was obtainable (this was mainly for Guns and AFV).

Trends in Other Areas - Aircraft

118. None of the projects for frontline military aircraft undertaken by CAC in the first half of the War measured up particularly well against the three Service criteria for success already cited. The Wirraway, although Mass Produced in the time of most usefulness to the Air Force, never reached the standard of Quality desired for a front line aircraft: CAC intended it to be a training aircraft. It was pressed into front line service only because of the grave shortage of aircraft in Australia during 1941-42. The Boomerang was a more serious attempt to design and produce a front line fighter, but it failed in Quality, in that it could not compete with the performance of enemy fighter aircraft. The Wirraway Dive Bomber was an imaginative development, but arrived

after the Australian participation in the Middle East (where it would have been of most use) had virtually ended. The jungles of the South West Pacific denied dive bombers adequate targets, and so such planes were hardly ever used. The Wackett Bomber suffered from developmental problems, and was eventually cancelled with only two aircraft having been made.

119. Most of these problems emanated from the very narrow base of Developmental and Manufacturing Design experience CAC had been able to obtain. Three of the four aircraft mentioned were based closely on the Wirraway. This was not CAC's fault as, in a technical sense, it had done extremely well. The results showed that time was needed to establish properly a satisfactory R and D Capability and Specialized Production Capability. The necessary range of skills and technical knowledge could only be acquired over long periods of training and experience. The war began too soon for CAC: this is the explanation as to why the Self Containment Strategy did not work out particularly well for this area.

120. CAC's major successes were the manufacture of the single and twin row Wasp aircraft engine, and the Mustang aircraft. The latter project was begun in 1944, and appears to have been a close copy of US models, with little attempt to introduce changes to design and manufacturing processes to accommodate local conditions. The Wasp project was an example also of the Strategy of the Technology Package, for the design was almost identical to US models, with no variation for local conditions, and the factory plant, machine tools and gauges were nearly all imported. This project proved impossible to expand into industry as it consisted of a largely alien set of industrial practices used on strange machine tools. Attempts to import more machinery from the USA failed; so that Australia was never able to supply all her own requirements of front line aircraft engines. Fortunately, the balance were able to be imported.

121. The Government's major attempt to make front line aircraft also ran into trouble. The Strategy of the Technology Package as represented by GAF's Beaufort project almost collapsed when Britain withdrew all support in July 1940 following the defeat of France. The project was saved when British authorities relented some months later, and resumed some limited supplies of components. However, GAF had now to assume much more responsibility for the production of components than had been originally intended. This aspect of the project was saved when it was discovered that many of the management and industrial techniques used in making automobiles were suitable for airframe manufacture and subcontracting. The major car companies took subsequently an extensive role in aircraft manufacture, but this could not prevent the Beaufort project from being delayed for 12 months.

122. More importantly, the choice of the Beaufort Bomber as the subject of the Technology Package Strategy was not made with enough care. The aircraft contained some serious developmental defects, which forced GAF into activities for which it was not well equipped, and which the Strategy had sought expressly to avoid. Among other things, the designated engines for the Beaufort airframe failed, there was a serious problem of stability associated with the tail

structure, and the wing shape was not appropriate for tropical air temperatures. These problems demanded the detailed skills of an R and D Capability. Fortunately, most of these problems also confronted the British, who brought their formidable aeronautical R and D Capability to bear. Unlike the AFV projects, GAF stuck closely to the British solutions, and adopted Australian solutions only for unique problems. The latter were solved by the R and D support from various Australian Universities, and the emerging, but as yet inexperienced, Aeronautical and Engine Testing Research Laboratory. In the former case the capability existed as a matter of accident, and not as a matter of Government Policy.

123. In the end, the Australian Beaufort Bomber reached the standards of Quality and Reliability demanded, and was Mass Produced successfully in the time of significant operational usefulness to the Air Force. It was probably Australia's most successful front line aircraft project conducted during the War. Its successor, the Beaufighter, had 60% commonality of components, and was also Mass Produced successfully to the standards of Quality and Reliability desired by the Air Force. The project probably achieved Mass Production during the period of operational usefulness to the Air Force, even though this was June 1944, when Japanese airpower had been broken. The Beaufighter proved to be most versatile, and was used effectively in a ground attack role.

124. The GAF experience showed that the Strategy of the Technology Package was vulnerable to war time disruption, because of its heavy reliance on overseas support. In the end, the GAF projects were only saved because more in-country Developmental Design, Manufacturing Design and Production Planning skill existed than had been recognised originally; and the main supplier was able to resume limited deliveries of components, and could give significant R and D support. If Specialized Production and R and D Capabilities had been established properly and earlier, in the style adopted by the MSB, and represented eventually by the Aeronautical and Engine Testing Research Laboratory, a better choice of aircraft, and a bolder in-country production effort could have been adopted sooner, without as much disruption.

125. The other major front line military aircraft to be made successfully in Australia according to all the Defence Force criteria, was the De Havilland Mosquito. This was a direct copy in almost all respects of the British original, except in the type of wood used. Since the use of wood was the most novel feature of the aircraft, the Australian departure was serious in a Developmental Design sense. However, significant R and D Capabilities in this area existed in several places, including the Division of Wood Technology of NSW Forestry Commission, the Division of Forest Products of the CSIRO, and De Havilland Australia. These resources helped to solve the problem of what wood to use, and how to glue it.

126. Despite these successes, the Australian front line aircraft production effort did not supply the majority of aircraft for the RAAF front line squadrons during the critical phase of the War. These came from Britain and the USA. Much more success was achieved in producing training aircraft such as the Wirraway. Australia supplied virtually all her own requirements, which in the end totalled many hundreds of different training aircraft.

Trends in Other Areas - Optical Munitions

127. All major military optical equipments were Mass Produced in Australia to the Defence Force standards of Quality and Reliability. Most of these were made during the period of their greatest operational utility, although they formed the longest lead time items in the full assembly of guns. This was a reflection of the inability to import appropriate machine tools, materials, and in some cases even manufacturing data.

128. It is believed that a process of improvisation was adopted in which scientists, working closely with production engineers from such companies as the Australian Optical Company and British United Shoe Machinery Company, devised the necessary machine tools, production planning and quality control. This leads to the tentative conclusion that the existence of an established R and D Capability for a light-industrial military technology, can also support the generation of a successful mass production effort, despite the absence of a Specialized Production Capability and overseas support. However, this could also result in such long lead times that the munition may lose its operational value before it reaches Mass Production.

Trends in Other Areas - Ammunition and Explosives

129. Ammunition and Explosives formed part of the programme of munitions development by the MSB. This was based on the Strategy of Self Containment. MSL formed the R and D Capability for both areas, and Ammunition Factory Footscray and Explosives Factory Maribyrnong the respective Specialized Production Capabilities. Over 50 explosives and ammunition projects were run during the War in Australia, and with a handful of exceptions, they all succeeded, i.e. they reached Service standards of Quality and Reliability, were Mass Produced, and were Timely. The Defence Forces were never short of ammunition for operational purposes; and Australia, in fact, also exported large quantities to Britain, India and New Zealand.

SUMMARY AND CONCLUSIONS

World War II Experience

130. The act of establishing military technologies in small powers is, in most cases, a question of transferring the technical knowledge from the Major Powers. Minor Powers do not usually have the Developmental Design, Manufacturing Design and Production Planning resources to generate independently new military technologies. (Paragraphs 1 to 8).

131. Small powers often need to modify this technical knowledge to accommodate unique operational requirements; and because their general (e.g. commercial) industry cannot be applied readily to the production of munitions. Such industry has in the past lacked many of the industrial capabilities demanded by the military technologies developed by the Major Powers; and so Manufacturing Design and Production Planning has had to be modified to allow successful production by the general industry of the small power. (Paragraphs 9 to 14).

132. A number of strategies can be defined which outline the different methods by which small powers can attempt to establish technological and industrial support for their Defence Forces for war. At one extreme a small power can establish for a particular technology an R and D Capability for modifying the Developmental Design of generic munitions, and an associated Specialized Production Capability to deal with the need to interpret and modify Manufacturing Design and Production Planning of the same munitions. This is called the Strategy of Self Containment. (Paragraph 15).

133. At the other extreme, the armed services of a small power can change their operational requirements to conform to the performance established by the Developmental Design of a munition from a major power; and attempt to boost the capability of local industry by importing factory plant, machine tools, jigs, gauges and components deemed necessary to manufacture such munitions by the same processes as described in the Manufacturing Design and Production Planning used by the Major Powers. This is called the Strategy of the Technology Package. No R and D and associated Specialized Production Capability are established for the relevant military technology. (Paragraphs 20 to 21).

134. Two other strategies exist between the extremes. The first is the Strategy of In-Country R and D; and consists of establishing an appropriate R and D Capability for the selected military technology, and of accepting totally the Manufacturing Design and Production Planning of the Major Power which designed the associated munitions. The second consists of establishing an appropriate Specialized Production Capability for the selected military technology, and of accepting totally the Developmental Design for the munitions of the Major Power. This is called the Strategy of In-Country Production Design. (Paragraphs 16 to 19).

135. Australian operational experience has shown that at least two of these strategies (Self Containment, and the Technology Package) were consciously applied by the Government for the World War II munitions production effort; and that a process of improvisation led to circumstances which were similar to one other strategy (In-Country R and D), allowing it to be examined as an indicator of the probable success which might have occurred had the Government applied the strategy consciously. (Paragraphs 33 to 40, 49-57, 41-47).

136. The comparative success of these strategies in establishing technological and industrial support for the Defence Forces in Australia has been measured according to whether each achieved the Defence Force standards of Quality and Reliability for the munitions being produced; and whether each achieved Mass Production for such munitions in Time for the products to still be of important military utility to the Defence Forces. (Paragraphs 58 to 70).

137. The Strategy of Self Containment was the most successful in attaining all Defence Force standards for munitions. The pattern of success was uniform across all military technologies on which the Strategy was applied (i.e. Explosives, Gun and Small Arms Ammunition, Guns, and Small Arms), with the exception of the early CAC aircraft projects. Here the main project (the Wirraway trainer) was entirely successful, but attempts to develop front line aircraft from it did not reach all of the Defence Forces standards. This was caused by the narrow base of aeronautical technical experience of the CAC scientists, and the restricted manufacturing experience of its engineers. The War had begun too soon for broader experience to be acquired, hindering the proper establishment of appropriate R and D, and Specialized Production Capabilities. This prevented the proper implementation of the Strategy of Self Containment for the technology for front line military aircraft in Australia. (Paragraphs 92,107,118 to 119,129).

138. The Strategy of the Technology Package was the least successful. However, this stemmed principally from the misapplication of the Strategy. The AFV technology area followed initially this Strategy; and then, in effect, attempted to switch to the Self Containment Strategy, without having provided an appropriate R and D Capability and Specialized Production Capability to supervise its modifications of proven overseas Developmental Designs, Manufacturing Designs, and Production Planning. This policy succeeded in giving AFV the faults of both Strategies and none of their virtues. The AFV area was almost uniformly unsuccessful in reaching Defence Force standards. Success attended the Strategy of the Technology Package when applied properly, as in the GAF Beaufort Bomber and Beaufighter projects. (Paragraphs 92 to 95,107,121 to 124).

139. However, even in its worst moments, the Strategy of Technology Package still succeeded in producing stop-gap munitions which assured the Defence Forces of some reliable form of supply during the most dangerous period of the War. Such munitions were usually of poor quality, but were better than no munitions at all. Thus even the AFV technology area succeeded at least to this

degree. The mistake of the Australian Government was that it allowed too many such enterprises (particularly the Tank projects) to continue well after such dangerous periods had passed, with the result that enormous resources were absorbed, which should have been redeployed on more useful munitions projects which could reach Defence Force standards. (Paragraphs 95 and 82 See also Reference 1, pp. 62-69 and History and Activities of the Branch of the Master General of the Ordnance 1939-1945, page 72)

140. If the Strategy of In-Country R and D had been implemented by the Government in peacetime, it probably would have proved to be successful. Examples such as optical munitions which followed the pattern of the strategy reasonably closely, showed the obvious benefit of an In-Country R and D Capability. Furthermore, the production of optical munitions reached generally the required Defence Force standards; but suffered a higher failure rate in reaching Timely Mass Production than munitions associated with the Strategy of Self Containment. This was caused by the difficulty of the Australian Government in importing key machine tools and gauges; and outlined the risk which can sometimes occur from relying on any degree of overseas support for a key area of military technology. (Paragraphs 127 to 128).

141. The effect of rising complexity, as measured by the number of industrial operations to produce a completed munition, was to extend lead times. The effect of complexity, as measured by lack of knowledge on how a munition was, or should be, designed and made, was to prevent munitions from reaching Defence Force standards. Such complexity was injected into munitions projects by the misapplication of the Strategies of Technological and Industrial Support. (Paragraphs 108 to 117).

Continuing Relevance of the Wartime Strategies of Technological and Industrial Support

142. Most smaller powers, including Australia, have procedures to identify capabilities, and hence munitions and their generic technologies, which are important to the strategic and tactical doctrine of their armed services. For a variety of reasons, including the possibility of disruption to overseas supplies, unacceptable lead times for overseas procurement, cost considerations and the impact of forecast usage rates, there are times when it becomes necessary to consider the supply of munitions from national industry sources.

143. The four strategies for technological and industrial support described in this note were derived originally in response to a request for assistance in 1981 from the Defence Working Group on Gun and Rocket Propulsion Technology. The strategies were tested against the experience of the study group, and were found to be a useful framework for analysis, especially in the way they helped to explain some of the occurrences in munitions production during World War II. While a definitive statement about the continuing relevance of the strategies to the strategic and technological circumstances of today is not appropriate to this note, some contributory observations can be offered.

144. In World War II, one predominant class of munitions for in-country production was that with high usage rates, in particular fire support munitions, of comparatively low unit cost. Today, one might expect that class of munition to still be relevant, while in addition a new class of high cost, hopefully low usage rate weapon, e.g. the guided missile, has emerged. By comparison with World War II types, all such munitions are in both an absolute and relative sense more technologically complex, reflecting the technological and tactical development in aspects of warfare germane to our region.

145. Strategic circumstances today are quite different from those of World War II and the advances in military technologies employed in munitions have not necessarily been reflected by parallel advances in manufacturing techniques and levels of precision in general industry. One informed writer put it this way - 'Consequently, countries other than the USA and Russia today face a technology gap between their commercial industry base and at least some of the demanding technologies of advanced military systems' (Reference 7).

146. Given that Australia was considering or had decided on local production, any of the Self Containment, In-Country R and D and Technology Package strategies could be applicable but this technology gap would not make their application any easier. All three strategies require specialised R and D activities, while two also require specialised production capabilities. The examples of World War II discussed in the preceding paragraphs emphasise the need to ensure the timely existence of the relevant specialised capabilities, and that their effective establishment took years, rather than months, to ensure successful in-country production. It seems likely that the technology gap has increased the relevance of this, given that production is to be undertaken.

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Annex A

THE CORRELATION BETWEEN TIME LOST AND CRITICAL PATH DELAYS

1. Table A1 lists data which has been divided into three groups on the basis of differing military technology. As many projects are listed for each group for which it was possible to obtain complete data, and reached Mass Production.

2. Linear regression was performed for each group with the following results:

a. Guns:

$$y = 0.93x + 0.18$$

where $r = 0.9297$
 $n = 9$

95% confidence limits for the estimated slope ± 0.31 .

b. Small Arms:

$$y = 1.12x - 0.92$$

where $r = 0.9750$
 $n = 5$

95% confidence limits for the estimated slope ± 0.42 .

c. AFV:

$$y = 1.23x + 0.06$$

where $r = 0.99$
 $n = 6$

95% confidence limits for the estimated slope ± 0.22 .

No slopes fall outside the 95% confidence limits of any other slope.

	CONFIDENCE LIMITS	SLOPE	CONFIDENCE LIMITS
Guns	0.63	0.93	1.24
Small Arms	0.70	1.12	1.54
AFV	1.01	1.23	1.46

3. Therefore, the hypothesis that the data from all three groups comes from the same population cannot be rejected. The combined data for all groups gave the following results:

$$y = 1.04x + 0.04$$

$$\text{where } r = 0.9414$$

$$n = 20$$

95% confidence limits for the estimated slope ± 0.18 .

4. Consequently, the assumption in the main text that each critical path delay lost about one month is supported by the data.

Table A1. TIME LOST AND CRITICAL PATH DELAYS FOR GUN, SMALL ARMS AND AFV PRODUCTION PROJECTS

MILITARY TECHNOLOGY	TIME LOST (Months)	NUMBER OF CRITICAL PATH DELAYS
	x	y
<u>Guns</u>		
3" Mortar	3	3
2 Pdr AT Gun	5	4
25 Pdr Field Gun	8	8
40mm Bofors	3	4
6 Pdr AT Gun	3	3
2" Mortar	3.5	3
17 Pdr AT Gun	3	4
4.2" Mortar	1	1
25 Pdr Pack Howitzer	3	2
<u>Small Arms</u>		
Bren Gun	5	5
Owen Gun	7	7
Hispano	3	3
Austen	2	1
Polsten	5	4
<u>AFV</u>		
AC1 Tank	8	10
Machine Gun Carrier	2	2
LP2, 3 etc.		
2 Pdr AT Gun Carrier	3	4
Scout Car	2	2
Light Armoured Car	1	2
3" Mortar Carrier	0.75	1

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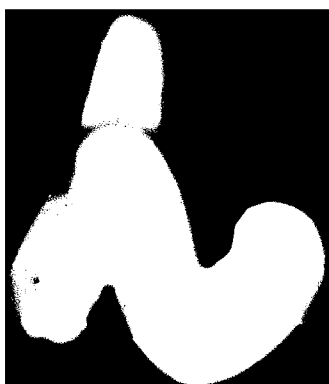
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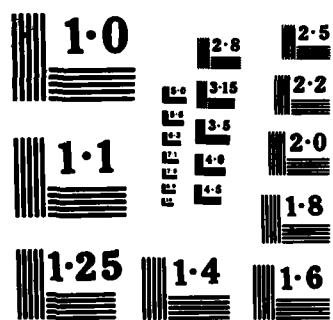
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16. Abstract This Note is a development of work carried out by CSE in 1981 to assist the Defence Working Group on Gun and Rocket Propulsion Technology. The author derives strategies available to a small power for the establishment of technical knowledge of munitions and the subsequent development of mass production. Australian preparation and experience in World War II is treated as a case study to determine the more robust of the strategies.			

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